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ADVANCE TECHNOLOGY FOR SPICES GRINDING - A REVIEW

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ABSTRACT

The main aim of this review is to summarize the knowledge of size reduction theory in grinding, working and importance of cryogenic grinding over convention method. Conventional grinding methods can be used to grind the species, but the problem of increase in the temperatures during grinding may lose the volatile oil compounds, natural flavour and aroma. But, in cryogenic grinding those quality attributes could be retained by using cryogenic liquids which maintains low temperatures during grinding.

KEYWORDS: Spices, Grinding, Cryogenics, Liquid Nitrogen & Energy Laws

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Original Article

INTRODUCTION

Spices have pungent flavour, taste and the medicinal properties. These are essential ingredients imparting taste and flavor to various food preparations. India is the leading producer and exporter of various spices i.e. fenugreek, turmeric, black pepper, coriander, and cinnamon etc (Barnwal *et al*, 2014).

Grinding is a process of increasing the surface area of solid materials by splitting into smaller particles. The accessibility of constituents such as oil inside the cells, fragrance and flavoring components that are presented in the material is increases due to increasing in their surface area (Murlidhar & Goswami, 2010). Different grinders are developed for this purpose those are attririon mill, hammer mill, ball mill etc. In grinding operation, only 1 % of applied energy is utilised for splitting of particles and remaining energy is dissipated as heat causes rising the temperature of ground product etc. Hence, it is a most power consuming operation. During grinding of spices, the temperature inside the machinery rises up to 42-93^0 C, which causes the loss of flavoring constituents and volatile oils. Sometimes, oil comes out from the material and makes the ground product sticky, gummy which results in chocking of product passage sieves (Singh and Goswami, 1997). Heat damage is one of the major disadvantages of the conventional grinding process, so it is especially significant to carry out the grinding under controlled temperature surroundings. Researchers developed a novel technology for the control of high temperatures during grinding, which is named as cryogenic grinding. With the help of cryogens, spices, essential food commodity and all of thermo-sensitive herbal medicines can be ground below their brittle temperature. The color and different properties of the ground product of cryogenic grinding will no longer be changed and their flavor and nutritional value will no longer be lost (Shimo *et al*., 1991). The appliance of this technology has been scientifically proved to be suitable method with less loss of volatile oil content, superior color and grinding operation. The high quality ground product would have good marketing. The present study involved in the theory behind the size reduction in grinding process and the cryogenic grinding process of spices.

Theory

"CRYOGENICS" originates from the greek phrase "cryo", which means that creation (or) production through cold. It deals with low temperatures as low as below **−150 °C or 123 K** to **absolute zero.** Cryogenics is the study of low temperatures and behavior of materials under these low temperatures.

Cryogens

The extremely low temperature is produced by using substances called "cryogens" such as liquid nitrogen and liquid helium etc. All cryogenic liquids are gases at ambient temperatures and pressures. So, those gases must be cooled below the ambient temperature to liquefy them. They have boiling points below -150°C (carbon dioxide and nitrous oxide, that have slightly better boiling points are sometimes covered in this category). There are several cryogenic liquids consisting of nitrogen, helium, neon, argon, krypton, hydrogen, methane and liquefied natural gas etc. Liquid nitrogen is the most normally used. Cryogens are stored in vessels referred to as as dewar flask which gives good insulation.

Liquid Nitrogen

It is similar appearance to water. Nitrogen gas makes up the major portion of the atmosphere (78.03% by volume). It is inert, odorless, colorless, non-flammable, non-corrosive liquid and extremely cold (boiling point -195.8° C). Volume of expansion liquid to gas (at 15°C, 1 atm) is 682, i.e. 1 litre of liquid nitrogen evaporated to form 682 litres of nitrogen gas. Vaporization of the liquid nitrogen to the gaseous state creates an inert and dry atmosphere for additional protection of spice quality. Liquid nitrogen in the Cryo-grinding process serves two purposes;

- To cool the raw material and the mill to operating temperatures
- To remove the heat liberated during grinding

Table 1: Properties of Cryogenic Fluids Used in Food Systems (Murthy *Et Al*, 2015)

Properties of Cryogens	LN_2	CO_2	Freon-12
Density (kg/m^3)	784	464	1485
Boiling point (^{0}C)	-196	-78.5	-29.8
Thermal conductivity (W/m k)	0.29	0.19	0.10
Specific heat capacity liquid (kj/kg k)	1.04	2.26	0.98
Latent heat of evaporation (kj/kg)	358	352	297

Cryogenic Grinding

Cryogenic grinding is also called as cry milling or freezer grinding. It is the process of size reduction of solid materials in the cooling environment created by cryogens to retain quality of ground product.

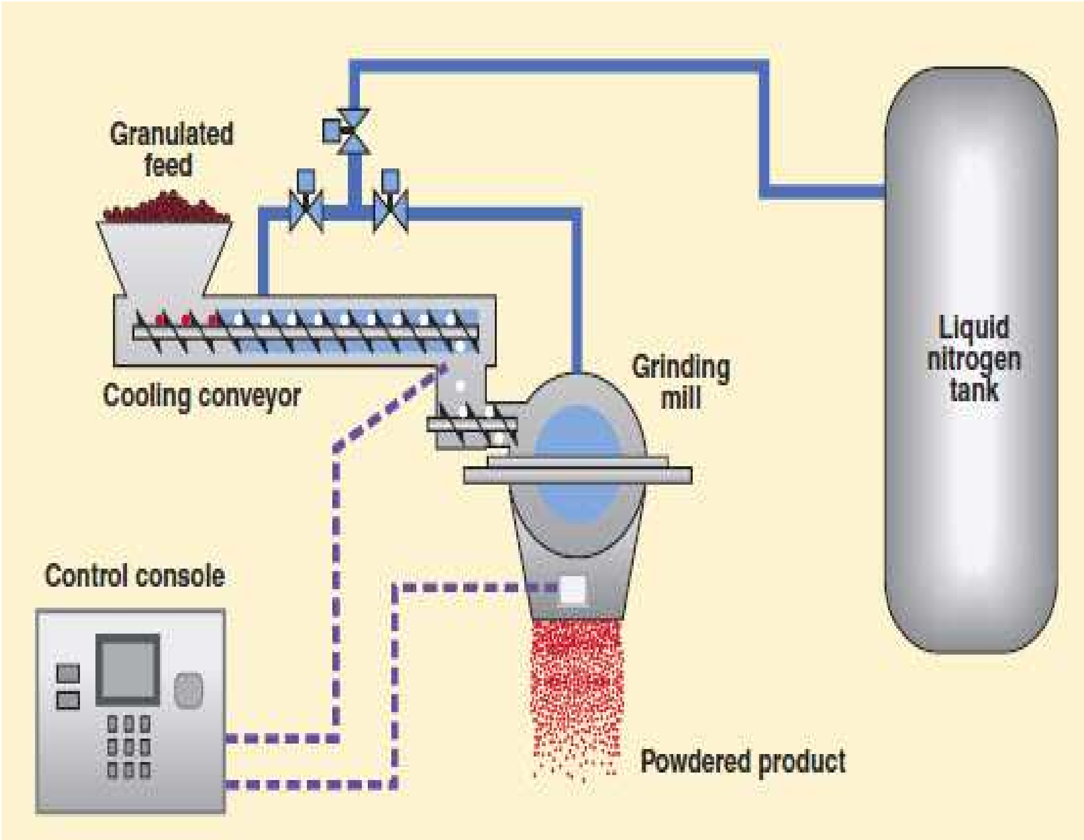

Figure 1: Cryogenic Apparatus

Following are the various components of cryogenic grinding machine:

Cryogenic Pre-Cooling

Figure 1 brings out the various components of the cryogenic grinding; the screw conveyor consists of screw made of aluminum. The length of screw is made larger than the length of shaft. The shaft is supported by two aluminum bushes fixed with flanges at both the ends. The screw shaft is enclosed in a long aluminum barrel. Both the ends of barrel are covered with flanges which are pressed at barrel ends and bushes. The shaft is enclosed in the barrel in such a way that a gap is to be maintained between the screw and the bottom portion of the inner surface of the barrel throughout the length, so that the material is not retained at the inner surface of the cage.

The barrel cage is insulated from outside with asbestos rope and asbestos powder throughout the surface to minimize the heat gain from the surroundings into the lead screw cage. At the upper portion of the barrel, a distributer is to be placed which can spray liquid nitrogen on the material which has to be conveyed through the barrel. The distributer is in the form of a long tube made with some material like copper. This tube consists of number of perforations such that the liquid nitrogen sprays out through them on the material. The distributer is placed at some particular distance from both the ends of barrel to have through mixing of liquid and vapor nitrogen with the material and to freeze the oil present in the material. This entire unit i, e screw, shaft and cage is placed on a frame made of mild steel.

Air Compressor

An air compressor of high speed is used to supply compressed air to liquid nitrogen tank. This air compressor is driven by single phase electric motor. The resulting pressure helps the liquid to flow out of the tank. The air compressor

has provision for automatic cut-off of the power supply at a particular air pressure. The air pressure at the outlet of the compressor can be varied with the help of a valve.

A double walled vacuum insulated tank is used for the storage and transfer of liquid nitrogen. An LN_2 transfer assembly is fixed over the tank to regulate the flow rate of the liquid nitrogen passing to the distributer attached to the conveyor assembly. A pressure gauge is also attached to the liquid nitrogen tank to indicate the pressure inside the LN_2 tank, a relief valve for protection against excessive pressure and a manual shut-off valve to control the LN_2 flow. A tube is also used to connect distributer and tank.

A single phase AC/DC motor is used to operate the conveyor. The electric supply is given through a variable speed AC/DC motor to the speed reduction unit. An appropriate gear reduction ratio can be maintained. The shaft of the gear reduction unit is coupled with the screw shaft through a coupling. This shaft has to be insulated to protect cold screw from worm motor. The speed of the Screw shaft can be varied by regulating the input voltage to the motor through a transformer. The feed rate and the retention time of the grinding material in the precooler are controlled to the desired levels by controlling the speed of the shaft. A collecting bin is placed at bottom of the mill to collect ground product.

Grinder

The main parts of the grinder are rotor rotating at peripheral velocities at range (nearly 20000-30000rpm). This rotor contains some ribs on it and is surrounded by sieve of trapezoidal opening sizes. The final product size depends upon the size of the sieve is selected by us.

The operation of grinding is obtained by the impact and attraction. The impact is achieved by material being struck with rotor ribs, where as attraction is achieved while seeds are present between the stationary sieve ring and fast moving rotor. The speed of the rotor can be controlled by an inbuilt control mechanism. The whole grinder is operated by an electric motor.

Table 2: Difference between Traditional and Cryogenic Grinding System

S. No.	Traditional Grinding System	Cryogenic Grinding System
1	The heat is developed inside the grinding mill	Temperature below $0^{o}C$ inside the grinding mill
2	The heat, which is developed during grinding, leads on one hand to evaporation of the essential oil and on the other hand, heat sensitive fats are melted.	Negligible loss of volatile component
3	This in turn can lead to the grinding elements become greasy (oily) and even harms the machine by blocking it.	Not in Cryogenic process
4	High energy consumption	Low energy consumption
5	High capacity motors are required to grind the material	Low capacity motors are required to grind the material

Size Reduction Theory in Grinding of Spices

The size reduction theory involves particle size analysis and power consumption in grinding (Sahay & Singh, 2004 and Geankoplis, 2004) etc. Different laws which explain energy requirement in grinding are described in the following subsections:

Energy Requirements in Grinding (Sahay & Singh, 2004)

The energy required in size reduction of materials is to overcome the friction in the moving parts of the machine

and to crush/grind the material/feed. When a feed is reduced to symmetrical particle of smaller size, the energy requirements must be related to some function of size of the feed and ground product. As per assumption, both the particles are symmetrical, a common dimension is used to calculate energy requirement. Therefore, the energy E is calculated by,

$$E = -c\int \frac{dx}{X^n} \tag{1}$$

Where, X is the length of particle in mm, n and *C* is constants.

Power required is calculated by the equation, $P = E \times f$ (2)

Where, f is feed rate (kg/hr)

Energy Laws in Grinding

Rittinger's Law: This law which states that the work required in crushing is proportional to the new surface developed. Therefore, energy requirement is proportional to the square of the common linear dimension, and thus value of n = 2. Then equation 1 becomes,

$$E = C\left[\frac{1}{X_P} - \frac{1}{X_F}\right]\text{.........} \tag{3}$$

Where, X_F and X_P are the lengths of feed and product respectively. Geankoplis (2004) reported that this law is valid in grinding of fine powders.

Kick's Law: This law states that within the elastic limit, the work required for crushing is constant for the same reduction ratio irrespective of their original sizes and thus value of n = 1. Then equation 1 becomes,

$$E = C\ln\frac{X_F}{X_P} \tag{4}$$

Bond's Law: This method is for estimating the power required for crushing and grinding operation. According to this law, the work required to form particle of size D_P from very large sized feed is proportional to the square root of the surface-to-volume ratio of the product. The value of n = 1.5 and the equation 1 becomes,

$$E = \frac{P}{f} = 0.3162\, w_i\left[\frac{1}{\sqrt{D_P}} - \frac{1}{\sqrt{D_F}}\right] \tag{5}$$

Where, D_F and D_P are the diameters of feed and product, respectively. w_i is working index, calculated experimentally from laboratory crushing and grinding tests.

Particle Size Analysis (Sahay & Singh, 2004)

Particle size analysis of ground powder can be carried out by using shaker setup and then calculating different diameter.

Fineness Modulus (FM): It indicates the uniformity of grind in resultant product. It is estimated by adding the weight fractions retained above each sieve and dividing the sum by 100.

$$FM = \frac{\textit{Total percent of weight fractions retained on sieve}}{100} \tag{6}$$

Average Particle Size (D_P): It is represented in terms of fineness modulus, which can be estimated by the following equation,

$$D_P = 0.135\ (1.366)^{FM} \tag{7}$$

There is a limitation in using above equation for determination of average particle size in ground product.

Total Surface Area (A): Total surface area of particles in ground product may be calculated as,

$$A = \frac{6}{\emptyset\ \rho_p\ D_P} \tag{8}$$

If the particle density(ρ_p) and its sphericity ($\emptyset$) are known, the surface area of particles in each fraction after sieve analysis may be calculated using above equation. In this case, the total surface area of particles will be the sum of particle surface areas in each fraction.

Specific Surface Area (A_{ss}): Considering particle density and sphericity as constant, the specific surface area of the total mixture of ground product could be calculated as,

$$A_{SS} = \frac{6}{\emptyset\ \rho_p} \sum_{i=1}^{n} \frac{m_i}{D_{Pi}} \tag{9}$$

Where, i = individual increment

- n = number of increments
- D_{Pi} = average particle diameter in each increment

Volume Surface Mean Diameter (D_{VS}): It is one way of representing the average particle size in a ground product. It can be calculated as,

$$D_{VS} = \frac{6}{\emptyset\ \rho_p\ A_{SS}} = \frac{1}{\sum_{i=1}^{n} \frac{m_i}{D_{Pi}}} \tag{10}$$

Mass Mean Diameter (D_m): It can be calculated from the equation as,

$$D_m = \sum_{i=1}^{n} m_i\ D_{Pi}. \tag{11}$$

Volume Mean Diameter (D_V): By dividing the total volume of ground product by the total number of particles in the mixture, the average volume of a particle can be obtained. Diameter of such particle is volume mean diameter. It may be expressed as,

$$D_V = \left[\frac{1}{\sum_{i=1}^{n} \frac{m_i}{D_{Pi}^3}} \right]^{1/3} \tag{12}$$

Number of particles in a ground material: It can be calculated by using the formula,

$$\text{No. of particles} = \frac{1}{a\ \rho_p\ D_V^3} \tag{13}$$

Where, a = shape factor

CONCLUSIONS

The main aim of this review is to summarize the knowledge of size reduction in grinding techniques, working and importance of cryogenic grinding over convention methods. Conventional grinding methods can be used to grind the species, but the problem is increase in the temperatures during grinding the maylosethe volatile oil compounds, natural

flavor and aroma. To avoid these losses, a new technique called cryogenic grinding emerged, which can retain the quality attributes of grinding materials. This technique using cryogenic liquids i.e. liquid nitrogen which maintains low temperatures during grinding thus reduces the losses.

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